

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

## **HIGH CAPACITY PASSIVE OPTICAL NETWORK**

### **FIELD OF THE INVENTION**

5 The present invention relates to apparatus and related methods of operation for providing a high capacity passive optical network, and a system incorporating the same.

### **BACKGROUND TO THE INVENTION**

This invention relates to fibre in the loop access networks, and in particular to fibre to the home (FTTH).

10 A characteristic of known FTTH networks is that customers tend to exist in groups situated geographically close to each other (say, within 200 metres), but the head end (or central office) may be some kilometres away for example, 5 km.

15 In networks where multiple nodes share a common medium, a multiple access protocol is needed to manage access to the medium such that individual nodes on the network can transmit their information successfully without interruption by transmission attempts from other nodes. Ethernet (IEEE standard 802.3) has adopted a 'Carrier Sense' with 'Collision Detection' protocol. When a node has data to transmit, it monitors the medium to check whether any other node is currently transmitting (Carrier Sense). If not, it is permitted to start transmission.

20 Other nodes on the network might also start transmitting when they detect that the medium is free, but might not know of other nearly simultaneous transmissions by another node because of the inherent transmission delay of the medium. Simultaneous transmission results in a 'collision' which must be detected by all nodes simultaneously attempting to transmit. Once a collision is

25 detected, each node ceases transmission and waits for a random time interval before sensing the medium and trying again.

Current implementations of Gigabit Optical Ethernet use point-to-point optical links to an 'unbuffered repeater' at the logical hub of the network. The repeater demodulates incoming signals from the point-to-point links and identifies a

30 collision when optical activity occurs simultaneously on more than one input.

It is also known to use a passive optical star coupler to interconnect nodes in an optical network. A star coupler has a number of inputs and outputs where an optical signal on any input appears (attenuated) at all coupler outputs. Various techniques are known for constructing passive star couplers. One common technique is to interconnect a number of simpler fused fibre couplers, each having two inputs and two outputs, to form a larger matrix with the required functionality. For example, an eight by eight star coupler can be made up from 12 two by two couplers.

For collision detection to work properly it is desirable (in the case of Gigabit Ethernet, mandatory) that any collision should be detected before a transmitting node has finished the transmission. For high speed networks such as these using a passive optical star coupler, this results in a tradeoff between the physical size of the network and the minimum length of the transmitted packet. For a network running at a nominal bit rate of 1Gbit/s and with an overall size of 5 km (typical of an access network) the minimum packet size to guarantee detection of a collision is around 6 kbytes.

30 A further problem is that, the maximum permitted packet size on an Ethernet network is around 1500 bytes; any network including Ethernet segments cannot therefore use a larger packet size than this unless data is reformatted.

Collision detection also requires that any transmitter must be able to detect reliably when more than one node is transmitting simultaneously. In a network interconnected with a passive optical coupler, tolerances in the port to port

coupler loss, differing attenuation in fibre connections between nodes and the passive coupler, and variations in node transmitter output powers combine to give a wide variation in optical signal level received at any node. It is then difficult to detect collisions, since a weak signal can be swamped by a strong one. Indeed, when practical tolerance levels are fully taken into account, it may not be possible to build a suitable receiver economically.

An earlier version of Ethernet, running at 10Mbit/s, included an option to operate collision detection in the optical domain using a passive star coupler (known in the standard as '10baseFP'). In practice, this system is rarely used because of the difficulty of implementing a receiver capable of reliable collision detection. The problems associated with implementing such a receiver can be expected to be much more severe at a bit rate of 1Gbit/s.

#### OBJECT TO THE INVENTION

The invention seeks to provide improved apparatus and method of operation for providing a high capacity passive optical network, and a system incorporating the same.

#### SUMMARY OF THE INVENTION

According to a first aspect of the present invention there is provided a passive optical network arrangement comprising:

- a head-end station;
  - at least one subscriber station;
  - a passive optical network providing optical connectivity from each of said stations to each other station;
- wherein said subscriber stations are arranged to transmit on a common optical frequency distinct from that on which said head-end station is arranged to transmit, and each of said subscriber stations is arranged to detect when another of said subscriber stations is transmitting over said passive optical network.

Advantageously, upstream packet size in the arrangement is independent of the distance between the subscriber stations and the head station, though still dependent on the distance between subscriber stations. This allows the head-

5

10

15

20

25

30

In such an arrangement, collision detection at a station involves a comparison between the newly sent signal and the received signal. A collision has occurred

5

10

15

20

25

30

a medium access logic unit arranged to prevent transmission on said first frequency while said transmission detector is detecting said signals from a

In a preferred embodiment, the transceiver further comprises:

Advantageously, the transceiver may receive data on the second frequency independently of signals received on said first frequency.

a common input port arranged to receive both said signal on said first optical frequency and said signal on said second frequency;

Advantageously, only a single input port is required, thereby reducing subscriber equipment and network cost.

Advantageously, this reduces the complexity required in the transmission detector circuitry. In particular no complex circuitry is required to compare a recently transmitted signal with the received signal to determine whether the received signal is or is not indicative of a transmission by another subscriber station

Advantageously, this reduces size and cost of the subscriber station equipment.

In particular there is provided a method of operating a passive optical network arrangement comprising:

at least one subscriber station;

5 comprising the steps of:

at least one of the subscriber stations detecting when another of said  
10 subscriber stations is transmitting on said common optical frequency over said  
passive optical network.

transmitting data on a first optical frequency;

preventing transmission on said first frequency while said transmission detector is detecting said signals from a network indicative of a transmission by another subscriber station on said first frequency .

The preferred features may be combined as appropriate, as would be apparent to a skilled person, and may be combined with any of the aspects of the invention.

In order to show how the invention may be carried into effect, embodiments of the invention are now described below by way of example only and with reference to the accompanying figures in which:



Figure 1 shows a block diagram of a example of a system in accordance with the present invention;

Figure 2 shows a schematic diagram of a first example of a non-return optical coupler in accordance with the present invention;

5 Figure 3 shows a schematic diagram of a second example of a non-return optical coupler in accordance with the present invention.

Figure 4 shows an further embodiment of a star coupler arranged for 3-fibre working;

10 Figure 5 shows a still further embodiment of a star coupler arranged for 2-fibre working;

Figure 6 shows a block diagram of an example of a further system arranged to make use of a non-return optical coupler.

#### DETAILED DESCRIPTION OF INVENTION

15 Referring now to Figure 1, there is shown a CS/CD network suitable for use as an access network, and comprising a single head end 25 connecting to a number of subscriber outstations 21-23 via a passive optical star coupler 20. Typically, the distance between any two outstations is assumed to be relatively small, perhaps 200 m, but the distance from the head end to the coupler may be much greater, for example up to around 5 km. The coupler may be located at a convenient point close to the subscribers' outstations (for example in a street cabinet) and, being a passive arrangement, requires no electrical power supply.

20 Each outstation comprises an optical transmitter 211 transmitting on frequency  $\lambda_1$  and controlled by a medium access logic unit 210, and an optical receiver arrangement 212 arranged to receive signals on both frequency's  $\lambda_1$  and  $\lambda_2$ .

25 The optical receiver arrangement may receive signals on both  $\lambda_1$  and  $\lambda_2$ , and splits them by means of demux 2124, providing the data signal on  $\lambda_2$  to a data receiver 2122, and signals indicative of collisions to a CS/CD receiver 2123.

30 When a given outstation has information to transmit, the outstation CS/CD receiver 2123 first monitors the incoming fibre 271 for optical activity from other outstations. If no such activity is present, the medium access logic 210 allows the transmission to start.

**Abstract**

5

10

15

20

25

30

Optionally, the head end 25 can be connected to the star coupler 20 using a single optical fibre 26 (instead of a fibre pair) by adding wavelength multiplexers at each end of the fibre connection.

5 To increase the downstream capacity of the network, either initially or as an upgrade to an existing network, traffic in the downstream direction could use multiple wavelengths, each wavelength being detected at one or more outstations using wavelength selective filters installed either in the outstations or at the coupler site. In this way, an asymmetrical network is generated, having larger capacity in the downstream direction.

10 Turning now to figure 2, there is shown a particularly preferred embodiment of a optical star coupler suitable for use in such an optical network.

The coupler has five receive ports 1R-5R and five corresponding transmit ports 1T-5T. The ports are logically paired so that, for example input 1R is paired with output 1T, 2R is paired with output 2T, etc. In many possible applications of the  
15 coupler, it is anticipated that such a pair of ports would be coupled to an optical fibre, or pair of fibres, leading to a single network equipment.

The receive ports are connected to transmit ports by means of a lattice arrangement of optical power splitters 100 and optical pathways 110 in such a way as to convey signals received at any given receive port to each transmit port  
20 other than the transmit port with which the receive port is paired. Each splitter will have a theoretical power loss of around 3dB. The nature of the construction gives rise to a number of unused ports 120.

Where, as described above, a receive-transmit pair is coupled to single network  
25 equipment, this means that signals received from that equipment are broadcast to all other connected equipments, but not back to the originating equipment.

Referring now to Figure 3, there is shown a second star coupler, in this case supporting nine receive and transmit ports.

Preferred embodiments have  $2^n + 1$  port pairs, where n is an integer greater than  
30 or equal to 1, though for most envisaged applications, n will be at least 2.

Figures 2 and 3 each show how two by two fused fibre couplers can be arranged to construct larger couplers having the property that an optical signal on any input is directed to all output fibres, except to the output fibre corresponding to the active input - a 'non-return star coupler'.

Since a node's own transmitted optical signal is not returned by the coupler, any activity at the node's receiver can only result from transmissions from another node on the network. Thus, if any node detects optical activity whilst it is transmitting, then a collision has occurred. As a result, collision detection can be performed reliably by a much simpler receiver. For example, a simple light detector may be used comprising for example, a PIN diode.

Carrier sense works in the normal way.

Furthermore, since in such an arrangement only optical activity must be detected, rather than a specific bit pattern at the network operating bit rate, the optical receiver 2123 used for carrier sense and collision detection needs only a relatively low frequency response and can therefore be implemented more economically

The non-return coupler embodiments described above typically have an additional 3 dB loss in excess of the intrinsic N-way splitting loss. In an alternative embodiment shown in Figure 4, this excess loss is reduced to less than 0.5 dB, through the use of WDM and asymmetric splitting. This arrangement requires 3-fibre working - 1 fibre for upstream traffic, one for downstream traffic, and a third collision detect - to each subscriber station. The headend path does not require collision detection, since WDM is used to remove it from the collision detect domain.

In this arrangement, the optimised coupler has a large asymmetric split applied to the upstream wavelength, directing the largest proportion (for example 90%) of the transmit power from an outstation towards the output fibre 5R directed towards the headend. As a result, the "Activity Detect fibre outputs" 1AD-4AD will carry varying signal levels (derived from 90% or 10% splits of the original outstation transmit levels) dependant upon which outstation is transmitting. This difference in signal levels is not a problem since the activity detect threshold will be set to a value less than the minimum attenuated outstation signal level expected.

All other couplers in the arrangement may be standard symmetrical 3 dB couplers.

In a still further embodiment of a non-return star coupler, shown in Figure 5, the fibre count on paths to the outstations is reduced to two fibres - one for transmit/receive, and one for Activity Detect. In PON arrangements using such

star coupler, an additional WDM component is required in each outstation to separate the upstream and downstream wavelengths.

Note that in Access Network Arrangements using either of these two embodiments, the upstream direction can utilise either 2-fibre working or single fibre working with WDM split at the headend, since each fibre carries all upstream traffic.

Referring now to Figure 6, there is shown a further embodiment of a CS/CD network suitable for use as an access network, and comprising a number of subscriber outstations 31-33 connectors via a non-return passive optical star coupler 30. Typically, the distance between any two outstations is assumed to be relatively small, perhaps 200 m. The coupler may be located at a convenient point close to the subscribers' outstations (for example in a street cabinet) and, being a passive arrangement, requires no electrical power supply.

Each outstation comprises an optical transmitter 311 transmitting on frequency  $\lambda_1$  and controlled by a medium access logic unit 310, and an optical receiver arrangement 312 arranged to receive signals on the same frequency,  $\lambda_1$ .

The optical receiver arrangement is arranged to receive signals on  $\lambda_1$  at a data receiver 3122 and translates the received signals to the electrical domain. Data signals are then forwarded to the local node for further processing whilst a copy is passed to the CS/CD receiver 3123. Any signal received in this arrangement is indicative of another station transmitting.

When a given outstation has information to transmit, the outstation CS/CD receiver 3123 first monitors the incoming fibre 371, via receiver 3122, for optical activity from other outstations. If no such activity is present, the medium access logic 310 allows the transmission to start.

During a transmission, the outstation CS/CD receiver 3123 monitors the incoming connection for signal activity indicative of a collision. If a collision is detected, the medium access logic 310 ceases transmission and retries after a random time interval.

Upstream collisions are detected 52 at the head end by identifying and discarding incomplete or corrupted packets.

In the downstream direction, information transmitted from each outstation is directed to all outstation data receivers 3122, each of which filters the packets

based on addressing information in the packet header and passes relevant packets to the higher layers of the outstation system.

As in the embodiment of Figure 1, since a node's own transmitted optical signal is not returned by the coupler, any activity at the node's receiver can only result from transmissions from another node on the network. Thus, if any node detects optical activity whilst it is transmitting, then a collision has occurred. As a result, collision detection can be performed reliably by a much simpler receiver. For example, a simple light detector may be used comprising for example, a PIN diode.

Carrier sense works in the normal way.

Furthermore, since in such an arrangement only any signal activity must be detected, rather than a specific bit pattern at the network operating bit rate, the receiver 2123 used for carrier sense and collision detection needs only a relatively low frequency response and can therefore be implemented more economically

In summary this invention allows, inter alia, an access network to be built where the head end equipment and much of the fibre infrastructure can be shared between a number of end customers. The transmission efficiency is significantly increased by restricting the geographical span of the multiple access collision domain. This is achieved without requiring active electronic equipment in street locations. Further, the passive star coupler is expected to be highly reliable, so easy physical access is also not required. The multiple access protocol can be similar to that used for Gigabit Ethernet, offering the possibility of reusing existing technology.

Any range or device value given herein may be extended or altered without losing the effect sought, as will be apparent to the skilled person for an understanding of the teachings herein.